The effect of vacuum combined surcharge preloading soft foundation treatment on adjacent pile foundation

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Abstract. According to the land formation project of Shenzhen Marine emerging industry base, the influence of three kinds of reactor preloading, vacuum preloading, on the adjacent pile foundation at different distances is studied by two-dimensional finite element analysis method. The results show that (1) the closer the pile foundation is to the preloading construction area, the greater the overall deformation; the influence of reactor preloading treatment on the horizontal deformation of adjacent pile foundation is much greater than vacuum prepressing treatment and vacuum combined preloading treatment; the influence range of reactor preloading treatment on adjacent pile foundation is greater than that of vacuum preloading treatment and vacuum combined preloading treatment.(2) The closer the pile foundation is to the prepress construction area, the more the bending moment is affected; the influence of the combined preloading treatment on adjacent pile foundation is much greater than that of vacuum prepressing treatment; and the influence of the preloading treatment on combined pile foundation is greater than that of vacuum prepressing treatment on adjacent pile foundation.

Keywords: soft foundation；vacuum combined surcharge preloading；pile foundation；finite element analysis.

1 INSTRUCTION

Soft soil is widely distributed in the coastal area of China, this kind of soil layer generally has high water content, low bearing capacity, large pores and rich compressibility, the main methods of soft ground treatment are vacuum pre-compression method, heap load pre-compression method and vacuum heap load joint pre-compression method, which have been widely used in the field of water transportation, high speed railroads, highways, airports and other soft ground treatment.

And domestic scholars have carried out a lot of research on soft ground treatment on the surrounding environment, and the more representative foundation treatment methods mainly include the pile load pre-compression method and vacuum pre-compression method. For example, Jin, X.R [1], Yu, Z.Q [2], Chen, L.Y [3], Zhou, Q [4], Chen, H [5], and Indraratna, B [6] investigated the effect of vacuum pre-compaction method on the surrounding environment; Zhang, N.S [7] and Wu,

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H.R [8] investigated the effect of vacuum combined with heap-load pre-compaction method on the surrounding environment, and Li, Z.W [9], Wei, R.L [10], and Yan, S [11] studied the effect of stack-load and other factors on the surrounding environment. There are more researches on vacuum pre-compression method and pile load pre-compression method, but there are fewer researches on the change rule of internal force and horizontal displacement of pile foundation in the periphery by vacuum combined with pile load pre-compression method and comparative analysis of the rule with the other two methods [12].

In view of this, this paper for soft ground treatment measures on the neighboring pile foundation force and deformation characteristics of the problem, considering the pile foundation of different distance factors, the use of two-dimensional finite element method, to carry out the three kinds of pre-pressure soft foundation treatment on the neighboring different distances from the pile foundation of the internal force and the horizontal displacement of the law of change research, the results of the research on the soft foundation treatment of the environmental response to the similar projects with reference value and reference basis.

2 PROJECT OVERVIEW AND CALCULATION PROGRAM

2.1 Project Overview

The project is located in the northwest of Shenzhen Baoan Dakungang area of the waterfront area, is located in the Lingdingyang east side of the bay top of the Jiaoche Bay, the bay depth is shallow, the terrain is relatively flat, the overall trend of the east is high and the west is low. According to the project geological data, mud surface elevation in -0.14 ~ 0.10 between, engineering area soil layer from top to bottom for silt, clay, silty clay, silt, sand, coarse sand, residual accumulation of silty clay, fully weathered gneiss, strong weathering gneiss, high compression of silt soil layer bottom elevation of about -5 ~ -18 m. One of the silt, was a fluid-plastic state, with a high moisture content, high compression of the soil layer of poor physics and mechanics, silty clay soft plastic state is dominant. The silt clay is mainly in soft-plastic state, locally in fluid-plastic state, with high compressibility, low bearing capacity and other characteristics, and the engineering geology is poor.

2.2 Calculation Program

In this study, for the environmental impact of soft foundation treatment project in Shenzhen, the following three pre-compression schemes are mainly carried out to analyze the environmental impacts of heap load pre-compression, vacuum pre-compression and vacuum combined heap load pre-compression on the adjacent pile foundations at different distances (the distance from the right-most drainage wells is L=15.8m, 20.5m, and 25.3m), respectively.

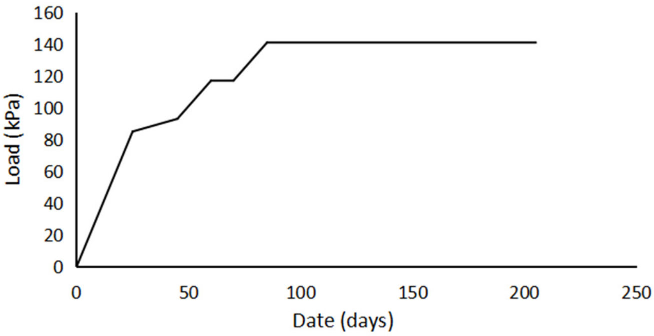


Fig. 1. Load plan

Scheme 1: Vacuum joint pile load pre-compression method adopts B-type drainage boards with spacing of 1.0m, arranged in a square, the length of drainage boards is about 15 m. After the horizontal drainage system is arranged, then 0.5m thick working mat is laid, and after the vacuum is stabilized, the pile continues to be stacked, and the pile adopts graded stacking, and the load is unloaded after 120 days of full-load pre-compression. The loading plan of vacuum joint pile preload is shown in Figure. 1 below. 3 pile bases with different horizontal distances are set up on the right side from the drainage board to establish three vacuum joint pile preload models.

Scheme 2: The pile load pre-compression method adopts graded pile loading, each time the superimposed load is 3m, and the load is removed after 120 days of full load pre-compression. Three pile foundations with different horizontal distances are set up respectively on the right side from the drainage board to establish three kinds of pile load pre-compression models.

Scheme 3: Adopt vacuum pre-compression method and vacuum joint pile load pre-compression method Drainage plate setup is the same, and the construction working condition is the same. Three pile foundations with different horizontal distances are set up respectively on the right side from the drainage board to establish three vacuum pre-compression models.

3 ANALYTICAL MODELS

3.1 Finite element model

According to the typical cross-section map of foundation treatment and the corresponding borehole histogram of the site, the vacuum-stacked load joint precompression construction area with a length of 80m×depth of 25m is taken to establish a pre-compression calculation model, and the width of the influence area is analyzed in agreement with the width of the calculation area. The left and right sides and the bottom are impermeable boundaries, and the thickness of both the first and second stage of stacking is 3m. In order to consider the influence of pile wall on horizontal displacement, the pile foundation on the right side of the soil pile, with a pile length of

17.75m, is 15.8m, 20.5m and 25.3m away from it respectively, and the depth of drainage board is 15m, and the specific computational model is shown in Figure.2.

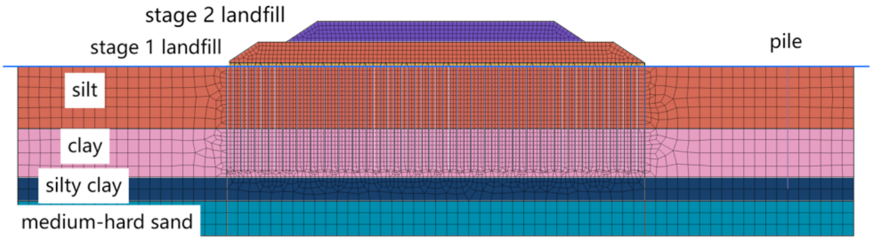


Fig. 2. Finite element model

3.2 Isomorphic model

The piles are modeled by linear elasticity model, and the foundation soils are modeled by Mohr-Coulomb model and Modified Cambridge model, which are calculated by using the Beale Consolidation Theory. The physical and mechanical parameters of each rock and soil layer are shown in Table 1 below.

Table 1. Physical and mechanical parameters of each rock and soil layer

soil layer	pile	stock-pile soil	sand bed-ding	silt	clay	silty clay	medi-um-hard sand
E	5000	30000	18000	10000	23000	29500	20000
v	0.2	0.3	0.32	0.45	0.35	0.37	0.3
c	-	15	2	-	-	20	0.1
φ	-	25	34	-	-	8	19
γ	25	13	18	14.6	18.1	16.5	18.8
e_0	0.5	0.05	0.5	1.86	0.87	1.4	0.68
OCR		-	-	1	1	-	-
λ	-	-	-	0.221	0.23	-	-
κ	-	-	-	0.015	0.042	-	-
M	-	-	-	0.18	0.25	-	-

4 CALCULATION RESULTS AND ANALYSIS

4.1 Impact of the construction process on the pile

Horizontal deformation.

Steps 1~7 in the stacked load pre-compression are the initial stage, the drainage board construction stage, the sand bedding construction stage, the first loading construction stage, the first resting construction stage, the second loading construction stage and the second resting construction stage, respectively. Steps 1~4 in the vacuum precompression are the initial stage, the drainage board construction stage, the sand mat construction stage, and the consolidation construction stage, respectively. Steps 1~8 in vacuum joint stacking pre-compression are the initial stage, drainage board construction stage, sand bedding construction stage, consolidation construction stage, first loading construction stage, first static construction stage, second loading construction stage and second static construction stage, respectively. The trend of maximum horizontal displacement of pile body at different construction stages for the pile foundations at L=15.8m, 20.5m and 25.3m from the rightmost side of the pre-compression construction area is shown in Figure. 3 as (a) (b) (c).

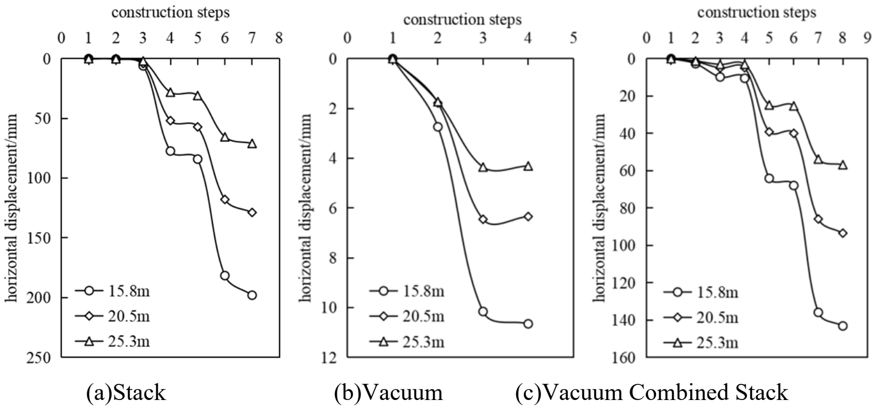


Fig. 3. Trend of horizontal displacement of pile during construction stage

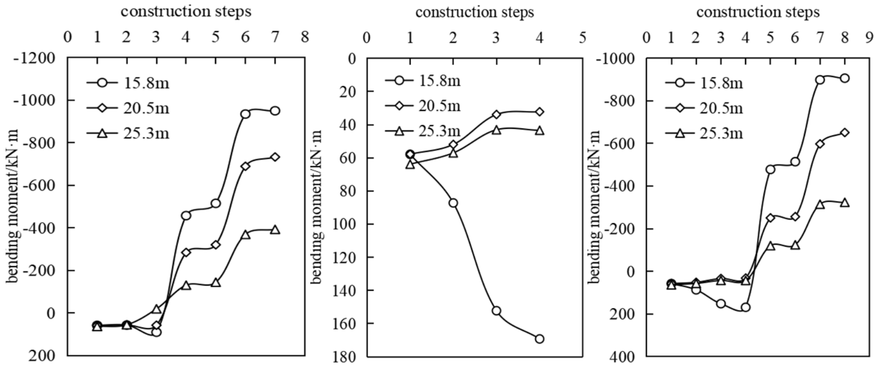
The horizontal deformation of neighboring piles in the construction process of pile loading pre-compression has the same law, the horizontal displacement of each pile changes obviously during the period of pile loading, and after the end of pile loading, the horizontal displacement of each pile increases slowly until it is stable. Up to unloading, the cumulative horizontal displacement of the pile at L=15.8m is 181.59mm, that of the pile at L=20.5m is 117.87mm, and that of the pile at L=25.3m is 65.45mm.The final cumulative horizontal displacement of the pile at L=15.8m in vacuum precompression is 10.16mm, that of the pile at L=20.5m is 6.45mm, and that of the pile at L=25.3m is 4.31mm.

The horizontal displacements of the piles in the vacuum combined pile load precompression varied significantly during the pile loading period, and the horizontal displacements of the piles increased slowly after the end of the pile loading until they stabilized. Up to unloading, the cumulative horizontal displacement of pile body at L=15.8m is 143.21mm, that of pile body at L=20.5m is 93.49mm, and that of pile body at L=25.3m is 56.84mm.The piles in the three types of precompression treatments gradually increase with the time of pile loading, and the closer the distance is, the greater the change of horizontal displacement is.

Deformation due to bending moment.

The trends of maximum bending moments of piles at different construction stages for pile foundations at L=15.8m, 20.5m, and 25.3m from the rightmost side of the precompression construction area for pile foundations with pile load pre-compression, vacuum pre-compression, and vacuum combined pile load pre-compression, respectively, are shown in Figure. 4 as (a) (b) (c).

The bending moment of the pile pre-compacted sand bedding changed slowly before the construction of the pile loaded pre-compacted sand bedding, and then deformed significantly, and the bending moment of each pile body increased significantly by the end of the pile loaded pre-compacted sand bedding. Up to unloading, the cumulative bending moment of the pile body at L=15.8m is 934.13kN-m, the cumulative bending moment of the pile body at L=20.5m is 688.84kN-m, and the cumulative bending moment of the pile body at L=25.3m is 369.07kN-m.



(a)Stack (b)Vacuum (c)Vacuum Combined Stack

Fig. 4. Trend of bending moment change of pile body during construction stage

The change of bending moment of pile body at the distance of 15.8m by vacuum precompression is obviously different and shows an increasing trend, which indicates that the vacuum precompression has a significant effect on the pile body in the range of about 15m, and the overall trend of the pile body at the distance of 20.5m and 25.3m is slowly decreasing. Up to unloading, the accumulated bending moment of the pile body at L=15.8m is 169.26kN-m, that of the pile body at L=20.5m is 43.40kN-m, and that of the pile body at L=25.3m is 32.21kN-m.

The bending moment changes slowly before the construction of vacuum combined pile loaded precompacted sand bedding and deforms significantly afterwards, and the bending moment of each pile body increases significantly after the end of pile loading. Up to unloading, the cumulative bending moment of the pile body at L=15.8m was 898.70kN-m, the cumulative bending moment of the pile body at L=20.5m was 597.72kN-m, and the cumulative bending moment of the pile body at L=25.3m was 314.67kN-m.

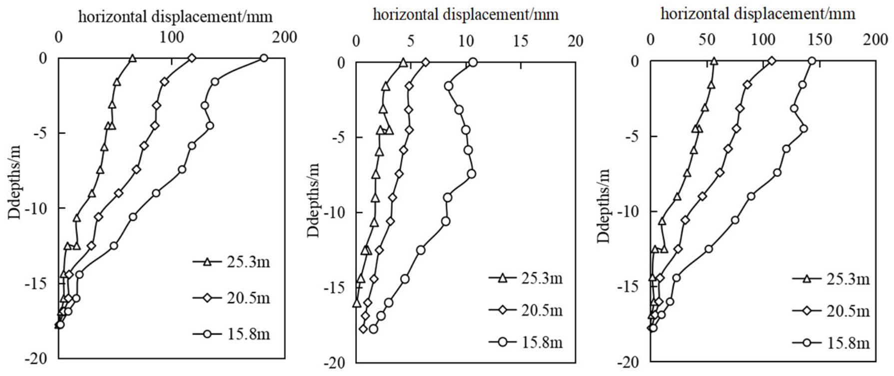
4.2 Effect of different precompression treatments on horizontal displacement of piles

The results of the horizontal deformation of the pile foundation on the rightmost side of L=15.8m, 20.5m and 25.3m from the precompression construction area by pile load pre-compression, vacuum pre-compression and vacuum combined pile load pre-compression are shown in Figure. 5 (a) (b) (c) respectively.

The distribution pattern of horizontal displacement along the pile body and the size of displacement in the three pre-compression treatments are basically the same, and the direction of displacement is far away from the reinforced area, which is specifically shown as the horizontal deformation increases from the bottom upward and away from the reinforced area continuously, and then decreases upward slowly after reaching the middle section, and then increases near the top at last. The maximum horizontal displacement of pile body in pile load pre-compression occurred at the top of the pile. As the horizontal displacement of the pile body gradually increases, the maximum horizontal displacement of the pile base at a distance of 15.8m reaches 181.59mm, and the maximum horizontal displacement of the pile base at a distance of 25.3m reaches 65.45mm, which is obvious, so the closer the distance is to the area of the drainage board, the more the horizontal displacement of the pile body increases, and the influence of the pile load pre-compression method around the periphery of the range of 25m away from it is significant.

The maximum horizontal displacement of pile body in vacuum precompression occurs at the top of the pile. The maximum horizontal displacement of the pile base at a distance of 15.8m reaches 10.36mm, and the maximum horizontal displacement of the pile base at a distance of 25.3m reaches 4.36mm, which does not change much, so the closer the distance of the pile base is to the area of the drainage board, the more the horizontal displacement of the pile body increases.

The maximum displacement in vacuum combined pile load pre-compression occurs at the top of the pile, and the closer the pile is to the center of the drainage board, the greater the change of horizontal displacement. The maximum horizontal displacement of the pile foundation at a distance of 15.8m reaches 143.21mm, and the maximum horizontal displacement of the pile foundation at a distance of 25.3m reaches 56.84mm, which is a more obvious change, and the periphery of the vacuum influence can reach a smaller range beyond 25m.



(a)Stack (b)Vacuum (c)Vacuum Combined Stack

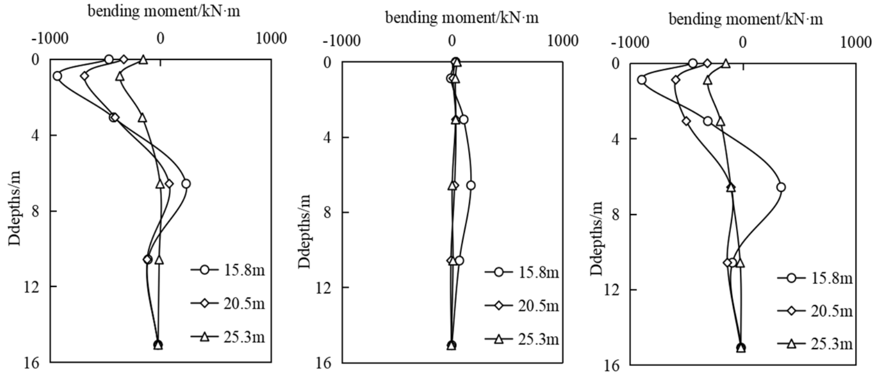
Fig. 5. Distribution of maximum horizontal displacement of pile after soft foundation treatment

4.3 Effect of different precompression treatments on bending moment of pile body

The calculation results of pile bending moments of pile foundations at L=15.8m, 20.5m, and 25.3m from the rightmost side of the precompression construction area by pile load precompression, vacuum precompression, and vacuum combined pile load precompression, respectively, are shown in Figs. 6(a)(b)(c). The variation of bending moments produced in pile foundations at three different distances in the pile load pre-compression was large, with the maximum values occurring near the top of the pile. As the distance between the pile foundation and the drainage board area increases, the bending moment deformation of the pile gradually decreases from 934.13kN-m to 369.07kN-m, which is obvious, but the influence range is still large.

The bending moment of the pile foundation at a distance of 15.8m in vacuum pre-compression is larger, mainly concentrated in the interface between clay and silt layer and near the upper part of clay, in which the maximum value appears near the clay layer; the bending moment of the pile foundation at a distance of 20.5m and at a distance of 25.3m is smaller, and the deformations occur in all the parts, which are all significantly smaller than that of the pile-load pre-compression method. As the distance between the pile foundation and the drainage board area increases, the deformation of the pile bending moment decreases gradually, from 169.26N-m to 32.21kN-m, the change is less obvious, but the influence range is smaller.

The bending moment of the pile body in the vacuum joint pile load pre-compression firstly decreases and then gradually increases, and the distribution law of the bending moment of the pile body of the three piles with different distances changes obviously, but the maximum value of the bending moment of the pile body of the three pile bases all appears near the upper part of the silt layer. The closer the pile body is to the precompression construction area, the change of the bending moment to the middle of the pile body decreases gradually, and the influence range can reach beyond 25m, and the maximum pile body bending moment deformation decreases gradually from 898.70N-m to 314.67kN-m, which is obvious, but the influence range is larger.



(a)Stack (b)Vacuum (c)Vacuum Combined Stack

Fig. 6. Bending moment distribution of pile body after soft foundation treatment

4.4 Comparative analysis

Three kinds of pile foundations according to the distance from near to far, the maximum horizontal displacement under the vacuum pre-compression method is 10.16m, 6.45m, 4.31m, the maximum bending moment is 169.26kN-m, 43.40kN-m, 32.21kN-m; the maximum horizontal displacement under the pile pre-compression method is 181.59m, 117.87m, 65.45m, the maximum bending moment is 934.13 kN-m, 688.84kN-m, 369.07kN-m; the maximum horizontal displacements were 143.21m, 93.49m, 56.84m, and the maximum bending moments were 898.70kN-m, 597.72kN-m, and 314.67kN-m under the vacuum combined heap load pre-compression method. The influence of three kinds of soft foundation pre-compression on the bending moments of pile foundations at different distances is as follows: The closer the pile foundation is to the precompression construction area, the larger the overall deformation is, and the smaller the bending moment is affected; the horizontal deformation and bending moment of the neighboring pile foundation by the pile load precompression treatment are much larger than that by the vacuum precompression treatment and the vacuum-pile load joint precompression treatment; and the range of the influence of the pile load precompression treatment on the neighboring pile foundation is larger than that by the vacuum precompression treatment and the vacuum-pile load joint precompression treatment.

5 CONCLUSIONS

Based on the specific engineering examples and the calculation results of the finite unit method, the effects of vacuum pre-compression, vacuum combined pile load pre-compression and pile load pre-compression soft foundation treatment on neighboring pile foundations were compared, and the following conclusions were drawn:

a) The maximum horizontal influence law of the three soft foundation treatments on pile foundations at different distances during construction is: the maximum displacement of pile foundations increases continuously with construction, in which the maximum displacement of pile foundations increases mainly in the loading and pressurizing stages; the maximum bending moment influence law of pile load pre-compression and vacuum joint pile load pre-compression on pile foundations at different distances during construction is basically the same, all of them show the maximum bending moment of the pile body before the pile load is Positive, and the maximum bending moment of the pile body increases rapidly in the negative direction during the pile loading stage. The maximum bending moments of pile foundations at different distances by vacuum pre-compression during construction are generally in the positive direction, and the bending moment of the nearest pile foundation decreases with the construction, while the bending moment of the other two pile foundations increases with the construction.

b) When the vacuum combined pile load pre-compaction method is used for soft foundation treatment, the final pile displacement is directed away from the reinforced area, the maximum horizontal displacement occurs at the top of the pile location, and the maximum bending moment of the pile body occurs near the upper part of the silt layer.

c) When the pile load pre-compression method is used for soft foundation treatment, the horizontal displacement direction of the pile body points to the outer side of the reinforced zone, the maximum displacement occurs at the location of the top of the pile, and the maximum bending moments of all three foundation piles occur near the top of the pile.

d) When vacuum pre-compression method is used for soft foundation treatment, the horizontal displacement of the pile body is directed to the side of the reinforced zone and the maximum displacement occurs at the location of the pile top, and the maximum bending moments of the pile foundations at distances of 20.5 m and 25.3 m both occur near the top of the piles while the maximum bending moments of the foundation piles at a distance of 15.8 m occur at the top of the piles and near the clay layer.

e) Among the different treatments, the pile foundation with vacuum pre-compression method has the smallest maximum horizontal displacement and maximum bending moment, while the displacement and bending moment of the pile foundation with vacuum combined pile load pre-compression method are significantly smaller than those of the pile foundation with pile load pre-compression method. In addition, the vacuum pre-compaction method has the smallest range of impact on the surrounding environment, the vacuum combined pile load pre-compaction method has moderate impact, and the pile load pre-compaction method has the largest impact on the environment.

REFERENCES

1. Jin, X.R, Yu, J.L, Gong, X.N. (2008) Experimental study on environmental effects of vacuum precompression and its prevention methods. J. Geotechnical Mechanics, 04: 1093-1096+1102
2. Yu, Z.Q, Zhu, Y.T, Yu, Z.F. (2001) Influence zone analysis of soft ground reinforcement by vacuum pre-compression method. J. China Harbor Construction, 01: 26-30.
3. Chen, L.Y, Zhu, J.C, Yi, N.G, etc. (2006) Finite element analysis of the influence range of vacuum prepressure reinforced soft foundation. J. Journal of Shenyang Jianzhu University (Natural Science edition), 01: 77-81.
4. Zhou, Q, Li, W, Gao, Y, etc. (2021) Analysis of the influence of vacuum prepressed soft foundation treatment on adjacent pile foundation. J. People Pearl River, 42 (05): 98-103.
5. Chen, H. (1991) Ten years of research on the mechanism of vacuum pre-compression. J. Port Engineering, 04: 17-26.
6. Indraratna, B, Rujikiatkamjorn, C, Kelly, R, et al. (2010) Sustainable soil improvement via vacuum preloading. J. Proceedings of the Institution of Civil Engineers - Ground Improvement, 163(1): 31-42.
7. Zhang, N.S, Chen, Z.J. (2019) Analysis of the impact of vacuum combined pile load pre-compaction on the surrounding environment based on virtual drainboard unit. J. China Harbor Construction, 39 (04): 17-21+82.
8. Wu, H.R, Yan, C.H, Xu, B.T, etc. (2013) Analysis of the effect of soft ground foundation reinforced by vacuum stacking combined with precompression J. Hydrogeology and Engineering geology, 40 (03): 74-78.
9. Li, Z.W. (2013) Study on the effect of soft ground adjacent pile load on bridge pile deviation. J. Geotechnics, 34 (12): 3594-3600.
10. Wei, R.L. (1982) Influence of large fill on neighboring pile foundation. J. Journal of Geotechnical Engineering, (02): 132-137.
11. Yan, S,Chu, J. (2005) Soil improvement for a storage yard using the combined vacuum and fill preloading method. J. Canadian Geotechnical Journal, 42(4):1094-1104.
12. Rujikiatkamjorn, C,Indraratna, B,Chu, J. (2008) 2D and 3D Numerical Modeling of Combined Surcharge and Vacuum Preloading with Vertical Drains. J. International Journal of Geomechanics, 8(2): 144-156.